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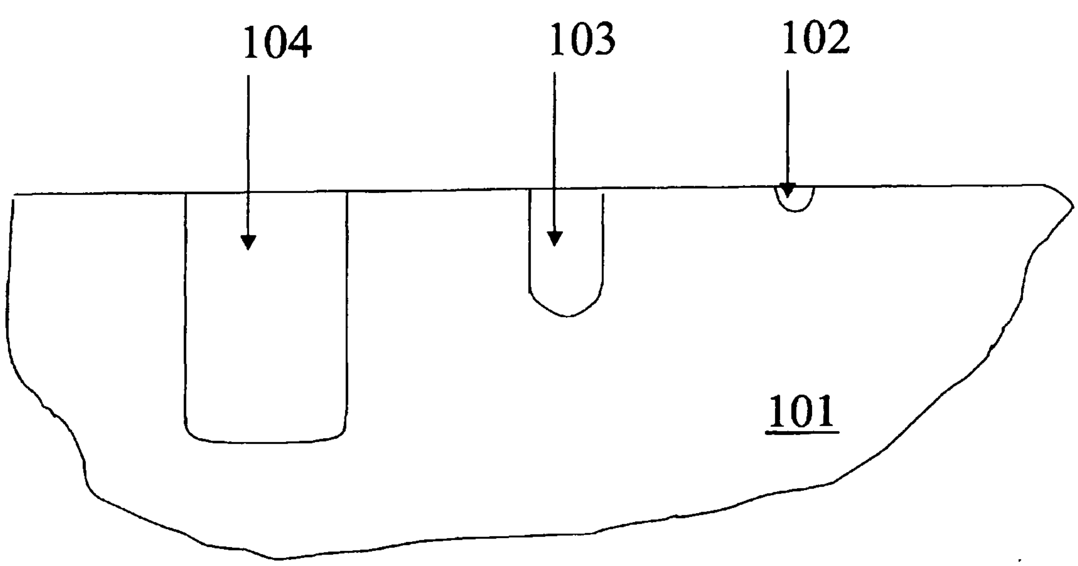
(54) Title: ABRASIVE BLAST MACHINING



(57) **Abstract:** A method of machining an article comprising the steps of:- a) forming a pattern of apertures in a mask, b) placing the mask on or adjacent the article and, c) directing abrasive materials against the mask to remove material from the articlein which the abrasive materials have a range of sizes, such that some particles are unable to enter some of the apertures in the mask.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

ABRASIVE BLAST MACHINING

This invention relates to an improved method of abrasive blast machining and is particularly, although not exclusively, applicable to manufacture of flow field plates for fuel cells and electrolysers (particularly, although not exclusively, for proton exchange membrane fuel cells and electrolysers).

Fuel cells are devices in which a fuel and an oxidant combine in a controlled manner to produce electricity directly. By directly producing electricity without intermediate combustion and generation steps, the electrical efficiency of a fuel cell is higher than using the fuel in a traditional generator. This much is widely known. A fuel cell sounds simple and desirable but many man-years of work have been expended in recent years attempting to produce practical fuel cell systems. An electrolyser is effectively a fuel cell in reverse, in which electricity is used to split water into hydrogen and oxygen. Both fuel cells and electrolysers are likely to become important parts of the so-called "hydrogen economy". In the following, reference is made to fuel cells, but it should be remembered that the same principles apply to electrolysers.

One type of fuel cell in commercial production is the so-called proton exchange membrane (PEM) fuel cell [sometimes called polymer electrolyte or solid polymer fuel cells (PEFCs)]. Such cells use hydrogen as a fuel and comprise an electrically insulating (but ionically conducting) polymer membrane having porous electrodes disposed on both faces. The membrane is typically a fluorosulphonate polymer and the electrodes typically comprise a noble metal catalyst dispersed on a carbonaceous powder substrate. This assembly of electrodes and membrane is often referred to as the membrane electrode assembly (MEA).

Fuel (typically hydrogen) is supplied to one electrode (the anode) where it is oxidised to release electrons to the anode and hydrogen ions to the electrolyte. Oxidant (typically air or oxygen) is supplied to the other electrode (the cathode) where electrons from the cathode combine with the oxygen and the hydrogen ions to produce water. A sub-class of proton exchange membrane fuel cell is the direct methanol fuel cell in which methanol is supplied as the fuel. This invention is intended to cover such fuel cells and indeed any other fuel cell using a proton exchange membrane.

In commercial PEM fuel cells many such membranes are stacked together separated by flow field plates (also referred to as bipolar plates). The flow field plates are typically formed of metal or graphite to permit good transfer of electrons between the anode of one membrane and the cathode of the adjacent membrane.

The flow field plates have a pattern of grooves on their surface to supply fluid (fuel or oxidant) and to remove water produced as a reaction product of the fuel cell. Flow fields may also be provided to supply coolant fluids. Various methods of producing the grooves have been described, for example it has been proposed to form such grooves by machining, embossing or moulding (WO00/41260), and (as is particularly useful for the present invention) by sandblasting through a resist (WO01/04982).

International patent application No. WO01/04982 disclosed a method of machining flow field plates by means of applying a resist or mask to a plate and then using sandblasting (or other etching method using the momentum of moving particles to abrade the surface, e.g. waterjet machining), to form features corresponding to a pattern formed in the mask or resist.

Such a process was shown by WO01/04982 as capable of forming either holes through the flow field plates, or closed bottom pits or channels in the flow field plates. The process of WO01/04982 is incorporated herein in its entirety, as giving sufficient background to enable the invention.To ensure that the fluids are dispersed evenly to their respective electrode surfaces a so-called gas diffusion layer (GDL) is placed between the electrode and the flow field plate. The gas diffusion layer is a porous material and typically comprises a carbon paper or cloth, often having a bonded layer of carbon powder on one face and coated with a hydrophobic material to promote water rejection. It has been proposed to provide an interdigitated flow field below a macroporous material (US-A-5641586) having connected porosity of pore size range 20-100μm allowing a reduction in size of the gas diffusion layer. Such an arrangement permits gas flow around blocked pores, which is disadvantageous. Build up of reactant products (such as water) can occur in these pores reducing gas transport efficiency. Additionally, such a structure increases the thickness of the flow field plate.

A combined flow field plate and gas diffusion layer has been described in US-A-6037073 and comprises a selectively impregnated body of porous carbon material, the impregnation hermetically sealing part of the plate. Such an arrangement has the drawbacks that it is complicated to make reproducibly and that it permits gas flow around blockages as in US-A-5641586.

An assembled body of flow field plates and membranes with associated fuel and oxidant supply manifolds is often referred to a fuel cell stack.

Although the technology described above has proved useful in prototype and in some limited commercial applications, to achieve wider commercial acceptance there is now a demand to reduce the physical size of a fuel cell stack and to reduce its cost. Accordingly, a reduction in the number of components could have beneficial results on size and cost (both through material and assembly costs). Also, the prior art flow field plates have provided flow fields of serpentine, linear, or interdigitated form but have not looked to other physical systems for improving the gas flow pathways.

The applicants have realised that a variety of improved flow field patterns may be achieved using abrasive blast machining and have realised that by tailoring the size distribution of abrasive particles used improved results may be achieved.

Accordingly, the present invention provides a method of machining an article comprising the steps of:-

a) forming a pattern of apertures in a mask

b) placing the mask on or adjacent the article

and,

c) directing abrasive materials against the mask to remove material from the article

in which the abrasive materials have a range of sizes, such that some particles are unable to enter some of the apertures in the mask.

Further details of the invention will become apparent from the claims and the following description with reference to the drawings in which:-

Fig. 1 shows schematically in part section a part of a fluid flow plate incorporating gas delivery channels and gas diffusion channels formed by an abrasive air blast technique (sandblasting).

Fig. 2 shows schematically a partial plan view of a fluid flow plate incorporating gas delivery channels and gas diffusion channels.

Fig. 3 is a schematic view of an abrasive gun for use in the invention;

To form both gas delivery and gas diffusion channels a technique such as abrasive blasting is used in which a template or resist is placed against the surface of a plate, the template or resist having a pattern corresponding to the desired channel geometry. Such a technique is described in WO01/04982, which is incorporated herein in its entirety as enabling the present invention.

With this technique the plates may be formed from a graphite/resin composite or other non-porous electrically conductive material that does not react significantly with the reactants used.

The type of abrasive blasting much preferred is the use of an air blast. Waterjet machining is generally found to be too aggressive for easy control, but with care and good control equipment would be possible.

It is found with this technique that the profiles of channels of different width vary due to the shadow cast by the mask. Fig. 1 shows a flow field plate 101 having a narrow channel 102 formed in its surface. Because of the shadowing effect of the resist used in forming the channel the channel is exposed to sandblast grit coming effectively only from directly above. This leads to a generally semicircular profile to the channel and to a shallow cutting of the channel.

For progressively larger channels (103 and 104) the resist casts less of a shadow allowing sandblasting grit from a progressively wider range of angles to strike the surface of the flow field plate, so allowing both deeper cutting of the surface and a progressively flatter bottom to the channel.

Accordingly, by applying a resist with different width channels to a plate and exposing the plate and resist to sandblasting with a fine grit, a pattern of channels of different widths and depths can be applied.

Applying such a pattern of channels of varying width and depth has advantages. In flow field plates the purpose behind the channels conventionally applied is to try to ensure a uniform supply of reactant material to the electrodes and to ensure prompt removal of reacted products. However the length of the passage material has to travel is high since a convoluted path is generally used.

Another system in which the aim is to supply reactant uniformly to a reactant surface and to remove reacted products is the lung. In the lung an arrangement of progressively finer channels is provided so that air has a short pathway to its reactant site in the lung, and carbon dioxide has a short pathway out again. By providing a network of progressively finer channels into the flow field plate, reactant gases have a short pathway to their reactant sites.

The finest channels could simply discharge into wide gas removal channels or, as in the lung, a corresponding network of progressively wider channels could be provided out of the flow field plate. In the latter case, the two networks of progressively finer channels and progressively wider channels could be connected end-to-end or arranged as interdigitated networks, with diffusion through the electrode material providing connectivity. Connection end-to-end provides the advantage that a high pressure will be maintained through the channels, assisting in the removal of blockages.

The question of interconnected channels vs. blind channels depends on which side of the electrode we are dealing with. Hydrogen ions travel from the anode, through the polymer, and are made into water at the cathode. All of the water is made on the cathode side (air or oxygen side) of the cell. The water generation on the cathode side means that the air side gas channels cannot be blind ended, as this would cause flooding. Interdigitated will also be tricky unless a GDL is used as the permeability of the electrode is not high. Interdigitated channels also restrict the removal of impurities from the supply gas. Accordingly, the model wherein the branched channels join end to end or drain to a larger channel is preferred.

Fig. 2 shows in a schematic plan a portion of a flow field plate having broad primary gas delivery channels 104, which diverge into secondary gas delivery channels 103 which themselves diverge into gas diffusion channels 102. Gas diffusion channels 105 can also come off the primary gas deliver channels 104 if required. The primary and secondary gas delivery channels may each form a network of progressively finer channels as may the gas diffusion channels and the arrangement of the channels may resemble a fractal arrangement.

The primary gas delivery channels may have a width of greater than 1mm, for example about 2mm. A typical depth of such a channel is 0.25mm but depth is limited only by the need to have sufficient strength in the flow field plate after forming the channel. The secondary gas delivery channels may have a width of less than 1mm, for example 0.5mm and, using the sandblasting technique may be shallower than the primary gas delivery channels. The gas diffusion channels have a width of less than 0.2mm, for example about 100μm and may be shallower still.

The flow field plates may be used with a gas diffusion layer, or the gas diffusion channels may be provided in a sufficient density over the surface of the flow field plate to provide sufficient gas delivery that a gas diffusion layer may be omitted.

When acting as a fuel cell, the gas delivery channels deliver gas to the gas diffusion channels which disperse the gas across the face of the flow field plate. When acting as an electrolyser the gas diffusion channels act to receive the gas from across the face of the flow field plate and the gas delivery channels deliver the gas for collection.

For the sandblasting technique, the limit on channel width is a function of the mask thickness used in the sand blast process. Image Pro™ materials (Chromaline Corp. US), are very thick at 125 micron. These masks limit track width to about 100 microns. Other mask materials can be spray coated onto the substrate and exposed in situ. These materials are much more resilient and hence can be much thinner. Chromaline SBX™ can be used to etch features down to 10-20 microns wide.

Various mask types may be used:-

a) adhesively mounted sheet masks

b) masks that are applied by painting, spraying, screen printing or any other such method to cover the desired surface of the article and then treated to selectively remove areas

c) masks that are applied and re-used

d) masks that are directly printed or applied to the surface (e.g. by ink blast printing)

the invention is not restricted to any particular form of mask, but types b) and d) lend themselves most readily to mass production.

Of course, the abrasive material used in the abrasive blast must have a finer particle size than the feature to be formed. However, finer particle size leads to a lessening in the abrasion rate. The applicants have found it useful to use a relatively coarse abrasive material in the blast (e.g. 50μm to 250μm diameter silica or alumina grit) to form the wide channels, followed by use of a fine abrasive material (e.g. 5-20μm diameter silica or alumina grit) to form the finer features. As explained further below, the coarse and fine materials may be mixed and applied in one step. The invention is not limited to any particular abrasive material.

Preferred materials for the plate are graphite, carbon-carbon composites, or carbon-resin composites. However the invention is not restricted to these materials and may be used for any material of suitable physical characteristics, with suitable choice of abrasive.

The use of angled blasts of abrasive materials is advantageous.

As abrasive particles in the blast will not go into apertures smaller than their diameter then it is evident that one could use angularly directed coarse abrasives to form large undercut channels and, in a separate normally directed blast, fine abrasives to form non-undercut fine channels.

Abrasives of a variety of sizes may be mixed to form a blend.

Fig. 3 shows an abrasive gun for use in such a technique in which a body 601 has an incoming high pressure gas supply pipe 602 and two abrasive delivery pipes 603 and 604.

The blast of air from pipe 602 draws in abrasive from delivery pipes 603 and 604 which may be independently regulated if desired. The blast of air incorporating the abrasive passes down pipe 605 which serves to restrict the divergence of the air blast. A typical divergence in conventional sandblasting would be about 10°, although this can be reduced by lengthening the pipe 605 or placing an aperture downstream of the pipe 605 exit to remove a portion of the blast having most divergence. If desired the blast can be spread by shortening the pipe or placing an impediment at the centre of the air blast to divert it sideways (in the latter case a loss of abrasive momentum would be seen).

Machining carbon-based materials by an abrasive blast method will produce a lot of carbon dust and means must be provided to deal with this and prevent it becoming an explosive risk. Use of air classifiers, or other such means for separating particles by size and/or weight, in the circulation of abrasive will permit the separation of the carbon and this can be disposed of, for example, by passing through a flame to burn it off.

Air classifiers will also allow the separation of fine abrasive particles from coarse and these can be passed to separate guns where required.

The separate integers and combinations described above may form inventions in their own right.

CLAIMS

1. A method of machining an article comprising the steps of:-

    a) forming a pattern of apertures in a mask

    b) placing the mask on or adjacent the article

    and,

    c) directing particles of abrasive material against the mask to remove material from the article

    in which the particles of abrasive material have a range of sizes, such that some particles of abrasive material are unable to enter some of the apertures in the mask.

2. A method as claimed in Claim 1, in which the abrasive materials comprise a relatively coarse material and a relatively fine material directed successively against the mask.

3. A method as claimed in Claim 1, in which the abrasive materials comprise a relatively coarse material and a relatively fine material directed simultaneously against the mask.

4. A method as claimed in any preceding claim, in which the abrasive materials comprise a relatively coarse material directed in an angled blast against the mask, and a relatively fine material directed perpendicularly against the mask.

5. A method as claimed in any preceding claim, in which used abrasive is separated into relatively coarse and relatively fine fractions and recycled.

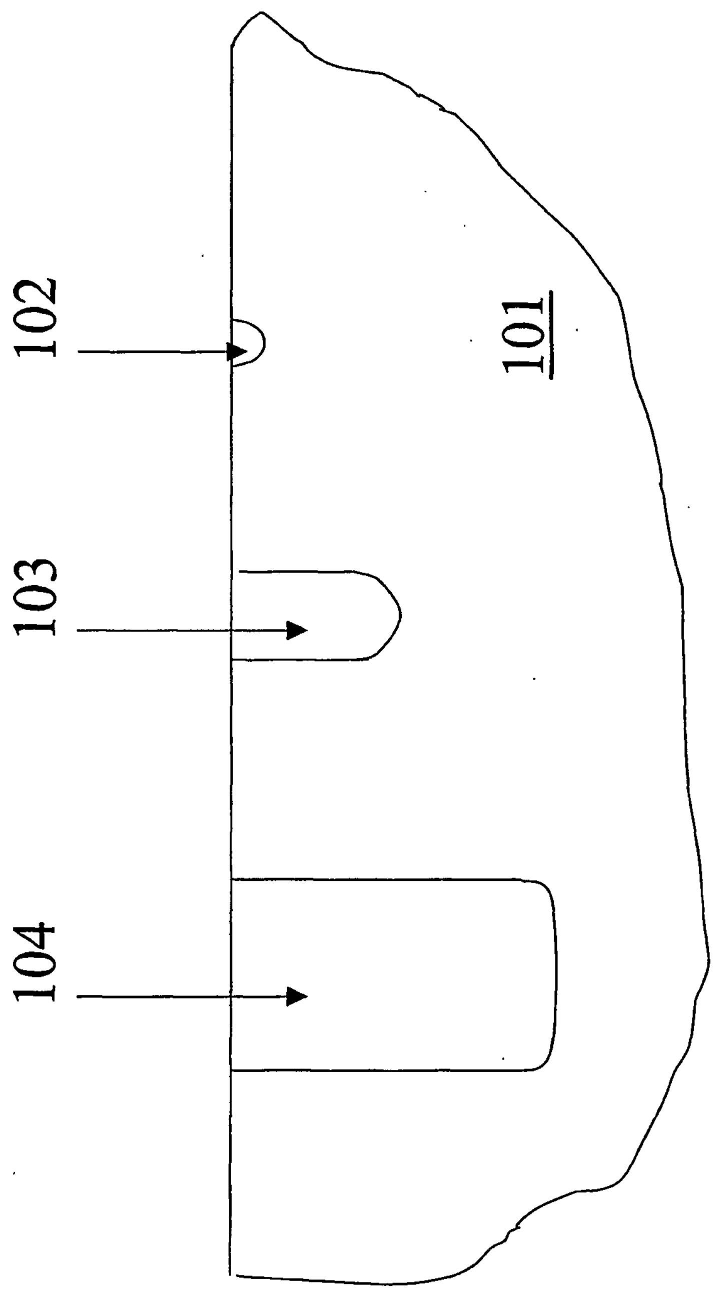
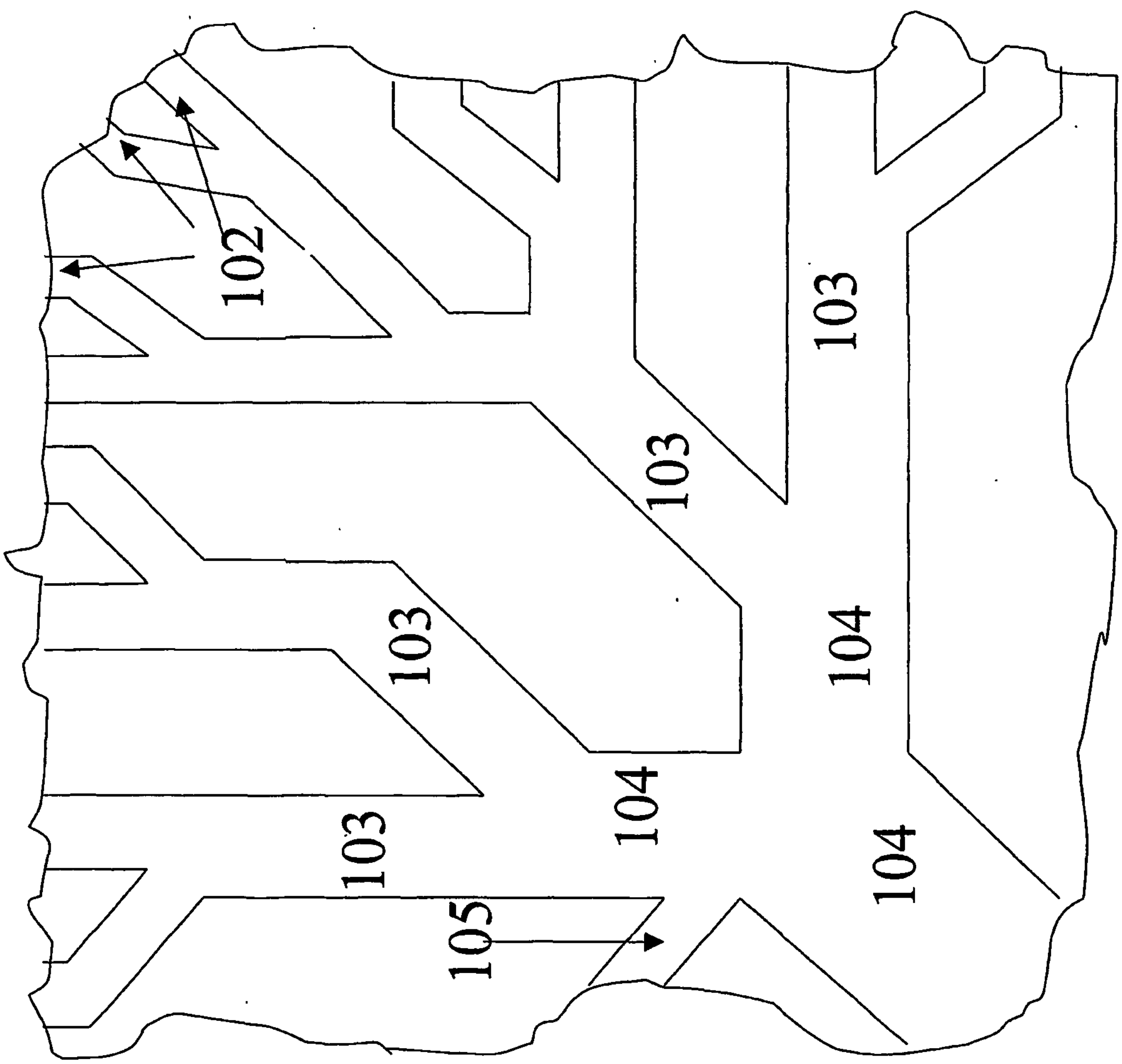


Fig. 1

Fig. 2



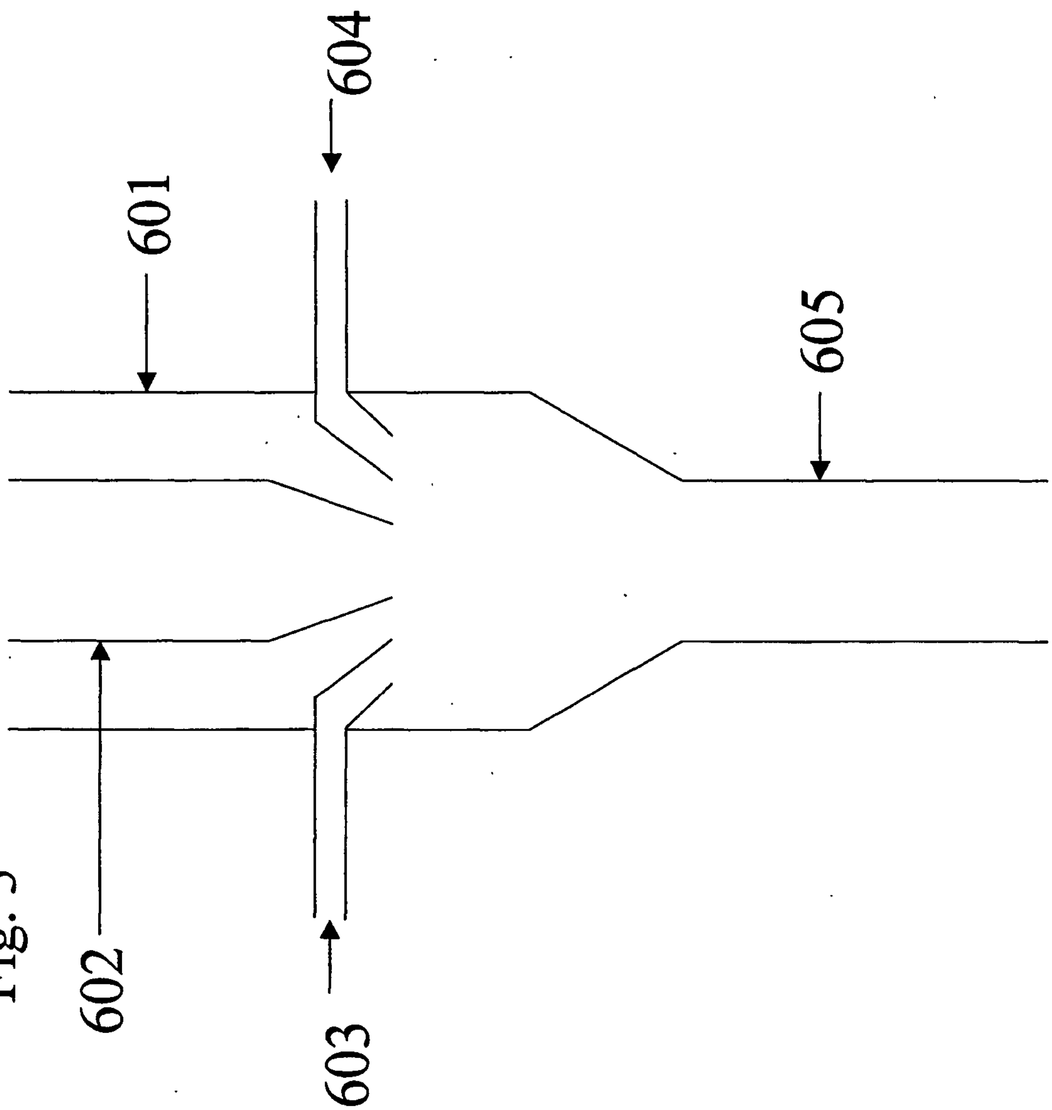


Fig. 3

INTERNATIONAL SEARCH REPORT

Inte ional Application No
PCT/GB 02/01808

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B24C1/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B24C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 01 04982 A (LOUGHBOROUGH UNIVERSITY INNOVATIONS) 18 January 2001 (2001-01-18) cited in the application abstract page 7, line 25 -page 8, line 4; figures -----	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 August 2002	28/08/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Matzdorf, U

INTERNATIONAL SEARCH REPORT

Information on patent family members

Intl onal Application No
PCT/GB 02/01808

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 0104982 A	18-01-2001	AU 5698300 A	30-01-2001
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